International Conference on Environmental Systems

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Thermal Testing - From Standard to Extreme Conditions

Panel Discussion

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Company background

- What is JPL?
  - A federally funded research and development center operated for NASA by Caltech
- What does JPL do?
  - Robotic exploration of Space; planetary science; astrophysics
- Thermal-related environments seen by our missions
  - Cryogenic; vacuum and atmosphere; microgravity to 1g; high solar flux; high pressure (Venus);
- JPL has in-house test facilities to simulate much of these thermal environments and to characterize the performance of the flight hardware

Thermal Testing Practices at JPL

- Protoflight/Qualification thermal test program at lower levels of assembly for functional and workmanship verification
- Thermal development tests at lower levels of assembly for thermal design validation or characterization
- System thermal testing (STT) to validate the thermal design and verify functional integrity when the flight hardware system is exposed to simulated mission thermal environments.
  - Thermal design validation is accomplished through a combination of empirical testing and model correlation
  - Verifications for those functions that can only be assessed as a whole system.
  - Flight acceptance is also done during STT for proto-flight programs

STT Requirements at JPL

- Thermal Balance Testing
  - The T/B Test is a dedicated steady-state or periodically repeating transient thermal test conducted at the worst-case maximum and minimum test parameters. Testing covers more than one mission phase (e.g., hot/cold environment and/or operating/non-operating) and may require more than one flight hardware system configuration. The goal of this test is to validate the thermal design, which may also require transient simulation.
  - Goal is to have at least 3 T/B cases, two of which are more extreme than predicted for flight. Enables more robust model correlation.
- Functional Verification and Design Robustness Testing
  - Thermal design robustness is demonstrated by the system response to a temperature regime induced by off-nominal flight environments. This regime goes beyond the worst-case hot and cold temperatures established during the thermal balance test but is bounded by the FA limits.
  - Functional verification testing done at plateaus, including FA extremes, and must function predictably and within specification.

Other Thermal Balance Issues

- Test-oriented modeling
  - A dedicated GMM and TMM is generated to simulate the actual test environment
- Uncertainty of test prediction
  - Pre-test thermal predictions do not preclude the need for contingency planning
- Stabilization criteria
  - Varies depending on the system. 0.2 ^{o}C/hr for 3 consecutive hours is common.
- Correlation criteria
  - Varies depending on the system. $< 5\ ^{o}$C on temperatures and 10% on heater power is common

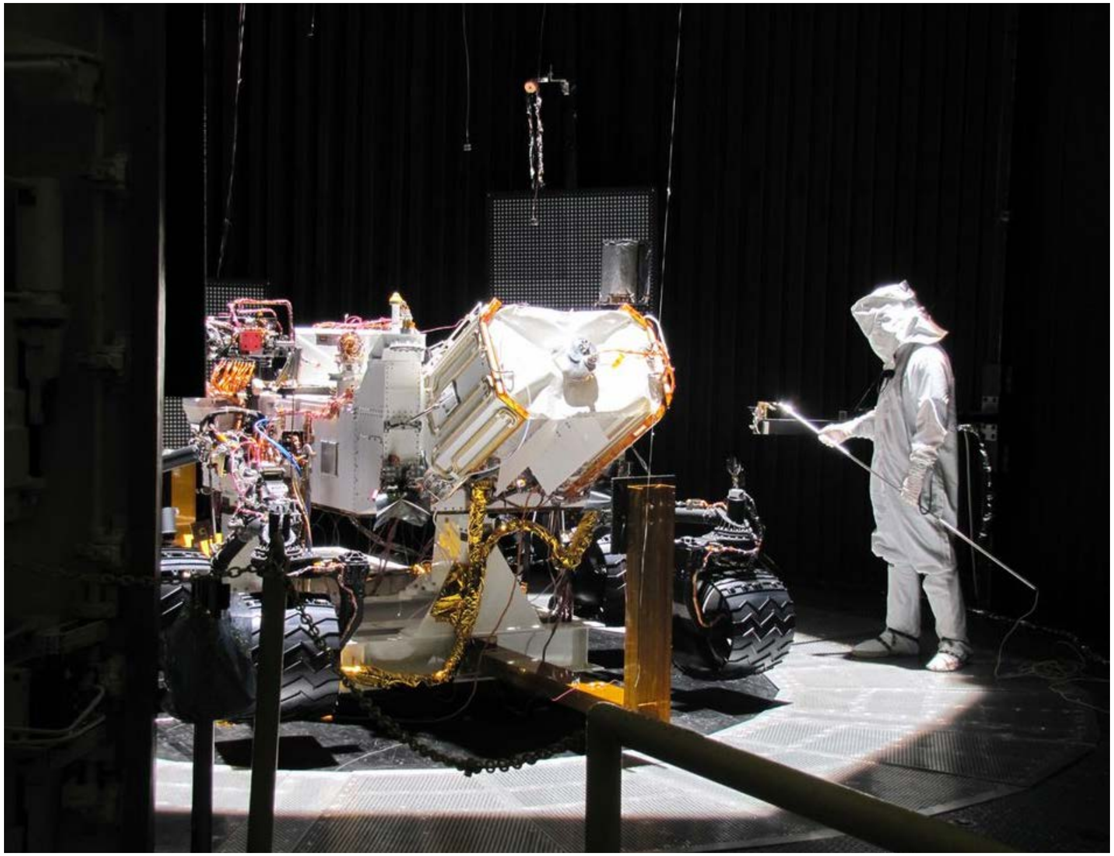
Lessons Learned

- Atmospheric simulation testing will require compromises to the Test as You Fly principle
- Solar simulation requires an understanding of the flux uniformity and spectral characteristics
- IR simulation can be difficult to configure. Dedicated calibration runs using radiometers is often required.
- Knowing your boundary conditions is often more important than striving for a high degree of empiricism

Testing Examples at JPL

Solar and Atmospheric Simulation Testing at JPL

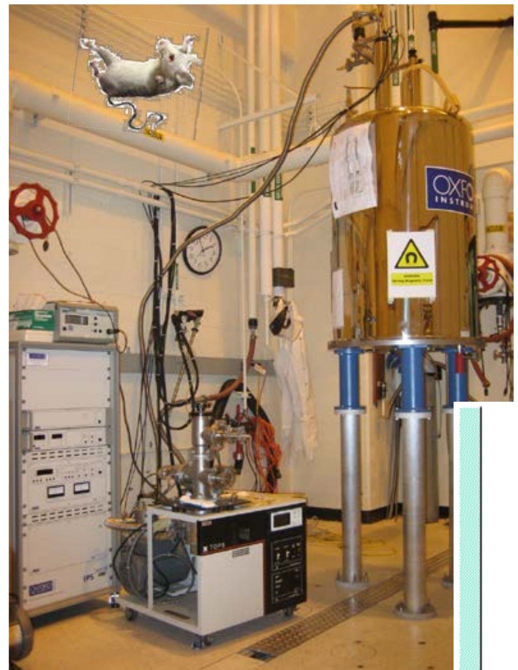
- MSL Rover testing in the JPL 25-ft Space Simulator
- Chamber capable of 2 Suns at 15-ft spot diameter
- 10 Torr GN2 used instead of CO2 for system safety

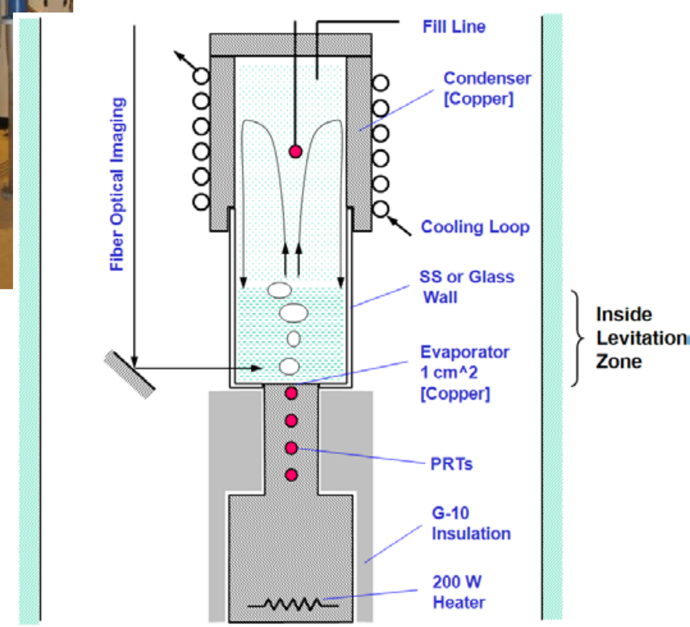


Solar uniformity mapping in preparation for MSL Rover STT

Two-Phase Thermal Testing in Microgravity at JPL

- Ground-based user facility to accommodate room-temperature and long-duration experiments or tests in variable gravities.
- Accommodate relatively large samples or scaled devices.
- Capable of simulating wide-range of gravities (0g to hyper-g) for common fluids.
- Supplements micro-g experiments in drop tower, KC-135 flights, Shuttle flights, and onboard ISS.
- Superconducting magnet run in persistent mode for long duration with low operation cost.
- Body force for levitation without mechanical disturbance.





Two-Phase Closed Thermosyphon

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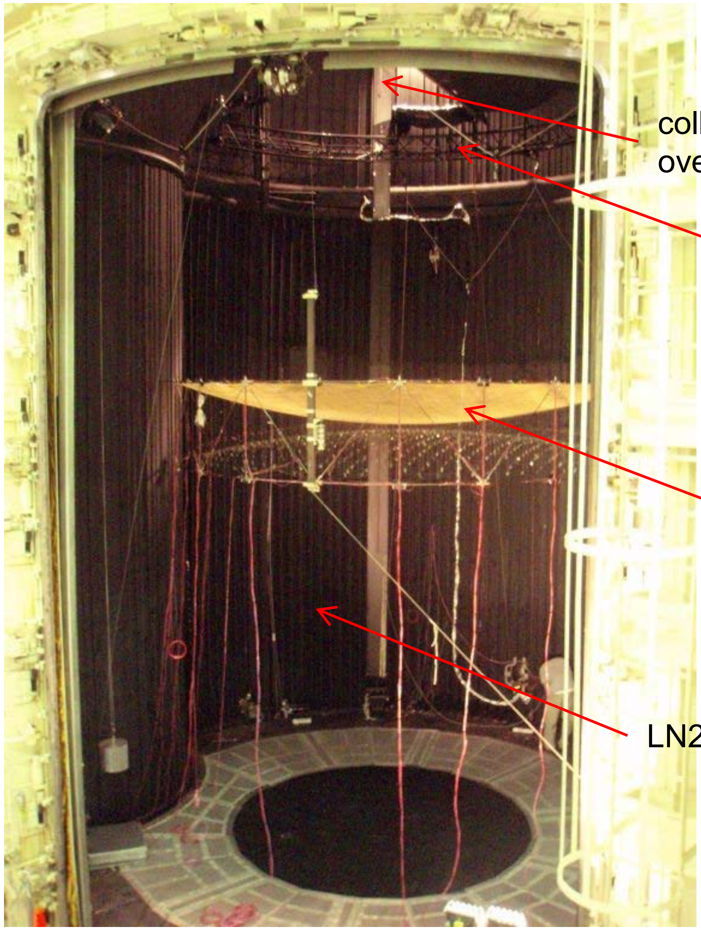
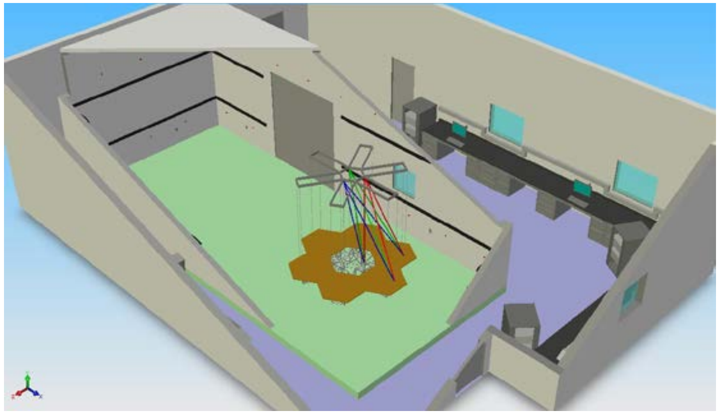
Integrated Thermo-Elastic Characterization Testing at JPL

- Test article: 5m aperture NGAS AstroMesh reflector
- Thermal disturbance: 1.25 Suns on half the reflector
- Deformation measurement technique: Photogrammetry camera system mounted on a cart/track system that traversed 270 deg of the solar simulator chamber's perimeter while keeping the test article in view.
- Achieved a resolution of ~30 microns over the 5m reflector aperture



Precision Environment Test Enclosure



JPL Precision Environment Test Enclosure (PETE): CAD view of the PETE inside Building 299 cleanroom, photograph of PETE with 8m deployable structure (SABUR - JPL/ATK/AFRL/CSA).

- **Precision Environment Test Enclosure** (**PETE**) in ALPS clean room
  - 10m x 5m x 3m test enclosure, mounted on isolator bearings. The PETE has structural mount points on walls and ceiling suitable for gravity offload systems, with a reinforced floor grid.
  - Provides thermal (<0.01 deg C per hr) and seismic (< 0.0001 G rms) and acoustic (< 35 dBA) stability for precision testing.
  - Dedicated metrology systems for the characterization of test hardware.

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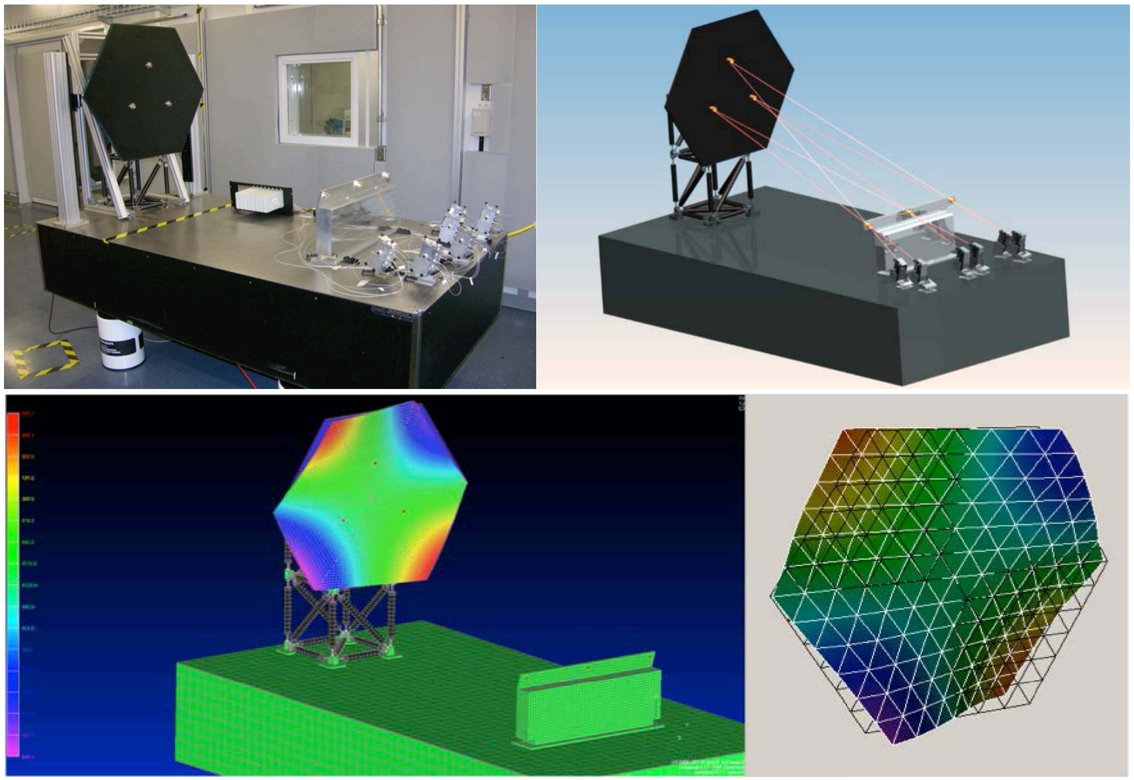
Example of a Test Measurement in PETE



Precision Deployable testbed article and interferometric metrology system. Top row: photograph and CAD view of the system in the PETE. Bottom row: modeled and measured natural frequencies of the panel.

- A parametric truss and panel are measured using an interferometric range-gated laser metrology system. Retroreflective target positions are measured to within 5 nm (relative) and 500 nm (absolute) at a distance of several meters.
- The thermal stability of the PETE prevents the air path from interfering with the laser system. This test would otherwise require installation in a vacuum chamber.

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